BLACK WARRIOR BASIN PROVINCE (065)

by R. T. Ryder

With a section on coalbed gas plays by Dudley D. Rice and Thomas M. Finn

INTRODUCTION

The Black Warrior Basin of northwestern Alabama and northeastern Mississippi is a foreland basin, containing Paleozoic sedimentary rocks, in the major structural re-entrant between the Appalachian and Ouachita Fold and Thrust Belts.

In a clockwise direction, starting in northernmost Alabama, the Black Warrior Basin is bounded by the following Provinces: Cincinnati Arch (066), Appalachian Basin (067), Louisiana-Mississippi Salt Basins (049), and Mississippi Embayment part of the Illinois Basin (064). Complexly block faulted Paleozoic strata dipping southwesterly away from the Nashville Dome, in the Cincinnati Arch Province (066), constitute the main framework of the basin. Frontal thrust faults of the Appalachian and Ouachita orogenic belts cut the southeastern and southwestern margins of the basin, respectively. Most of the basin, including its thrust-faulted margins, are buried beneath a veneer of Cretaceous and Tertiary strata of the Mississippi Embayment and Gulf Coastal Plain.

The Black Warrior basin covers an area of about 23,000 sq mi. From west to east, the basin is 230 mi long, whereas from north to south the basin is 188 mi wide.

Gas production in the Black Warrior Basin was first established in 1909 from a Pennsylvanian sandstone in Fayette County, Alabama, at a depth of 1,400 ft. In 1926 gas was discovered in Monroe County, Mississippi, from an Upper Mississippian sandstone at a depth of 2,400 ft. Exploration in the 1950's and early 1960's in the basin was concentrated in and around Monroe County and resulted in the discovery of several small gas fields and two noncommercial oil accumulations in Upper Mississippian sandstone reservoirs. The largest field discovered during this phase of exploration, Muldon field, produced gas from the Upper Mississippian Sanders sandstone at about 5,500 ft. The discovery of the East Detroit field in Lamar County, Alabama, in 1970 is considered by some to have been responsible for increased exploration activity in the 1970's and 1980's. Coalbed gas was first established in the basin (Tuscaloosa County, Ala.) in 1981 from the Mary Lee/Blue Creek and Pratt coal beds in the Lower Pennsylvanian Pottsville Formation. Gas production from this unconventional reservoir has steadily increased so that during 1991 it accounted for 75 percent of the 92.6 BCF of gas produced in the basin. Several deep holes were drilled to the Cambrian and Lower Ordovician Knox Group for gas accumulations akin to the giant Wilburton field in the Arkoma Basin of eastern Oklahoma. To date, all of these drill holes have been unsuccessful.

Through 1991, 90 conventional nonassociated gas fields, 15 coalbed gas fields, and 20 oil-associated gas fields have been discovered in the Alabama part of the basin. The dominant reservoir of the conventional gas and oil fields is the Carter sandstone of Late Mississippian age. The three largest nonassociated gas fields in the Alabama part of the basin are Blooming Grove, discovery date 1975, ultimate recovery 169.6 BCFG; Musgrove Creek, discovery date 1974, ultimate recovery 111.0 BCFG; and McGee Lake, discovery date 1979, ultimate recovery 105.9 BCFG. Most of the oil fields in the basin have an ultimate recovery of less than 1 million barrels; however, the Blowhorn Creek North and Maple Branch fields have an ultimate recovery of 14.5 and 2.0 million barrels, respectively.

Through 1991, 27 conventional nonassociated gas fields, 28 conventional gas-associated oil fields, and 9 oil fields have been discovered in the Mississippi part of the basin. The dominant reservoirs of the conventional gas fields are the Carter and Sanders sandstones of Late Mississippian age. The three largest nonassociated gas fields in the Mississippi part of the basin are Corinne, discovery date 1972, ultimate recovery 504.7 BCFG; Splunge, discovery date 1973, ultimate recovery 101.2 BCFG; and Muldon, discovery date 1952, ultimate recovery 99.7 BCFG.

The Black Warrior Basin has produced 1.15 TCF of gas (Alabama 662.2 BCF, Mississippi 491.1 BCF) and 10.6 MMBO (Alabama 8.5 MMBO, Mississippi 2.1 MMBO) through 1991.

The following conventional plays are recognized in the Black Warrior basin: Cambrian and Ordovician Carbonate Play (6501), Upper Mississippian Sandstone Play (6502), Pennsylvanian Sandstone Play (6503), and Devonian Chert and Carbonate Play (6505). Unconventional coalbed gas plays described by Rice and Finn are: Black Warrior Basin Recharge Play (6550), Black Warrior Basin–Southeastern Basin Play (6551), Black Warrior Basin–Coastal Plain Play (6552), and Black Warrior Basin–Central and Western Basin (6553). Further discussion of coalbed methane plays, and references, may be found in the chapter by Rice, “Geologic framework and description of coalbed gas plays” elsewhere in this CD-ROM.

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CONVENTIONAL PLAYS

6501. CAMBRIAN AND ORDOVICIAN CARBONATE PLAY (HYPOTHETICAL)

The Cambrian and Ordovician Carbonate Play is defined by gas and local oil trapped in Cambrian and (or) Ordovician platform carbonate reservoirs by basement-controlled fault blocks, ramp anticlines associated with frontal thrust faults, and facies changes. Stratigraphically, the play involves the Cambrian and Lower Ordovician Knox Group, the Middle Ordovician Stones River Group, and the Middle Ordovician Chickamauga Group. The play is hypothetical and extends across the Black Warrior Basin and the southern end of the Mississippi Embayment in northwesternmost Mississippi and adjoining Arkansas. The Mississippi Embayment part of the play consists of frontal thrust sheets and subthrust fault blocks of the Ouachita Fold and Thrust Belt where gas accumulations may be trapped in Cambrian and Ordovician carbonate rocks. Throughout the play, carbonate reservoirs are classified as conventional.

Reservoirs: Primary reservoirs in the play are vuggy dolomite and limestone formed by karst processes. Commonly, these reservoirs are overprinted with tectonic fractures. Reservoirs of secondary importance may have oomoldic and biomoldic porosity. Vuggy and (or) fracture porosity are capable of producing high-quality reservoirs in the Cambrian and Ordovician carbonate sequence, but, where identified, they are generally very discontinuous and heterogeneous.

The most extensive reservoir unit identified to date is the "Snow zone", a zone of vuggy porosity in an unnamed basal dolomite unit in the Middle Ordovician Stones River Group that is probably the result of subaerial exposure and karst processes. The "Snow zone" in Mississippi ranges in thickness from 3 to 340 ft and has yielded small quantities of oil and gas. Secondary zones of vuggy porosity, also caused by karst processes, are recognized in the "Pierce zone" (16 ft thick) of the Lower Ordovician sponge-algal limestone of the Knox Group and in unnamed zones (as thick as 256 ft) of the Lower Ordovician cherty and sandy dolomite unit of the Knox Group. Karst processes are also responsible for possible reservoir-quality vuggy and cavernous zones beneath regional unconformities such as the early Middle Ordovician Knox unconformity in Alabama and the post-Middle Ordovician unconformity in Mississippi.

Tectonic fractures of extensional and compressional origin have improved the reservoir quality of karst-related porous zones and, in some cases, may be the sole cause of the reservoir. Compressional fractures are generally confined to tectonic ramps, zones of detachment in frontal thrust faults, and local zones of transpression between basement-involved fault blocks. Extensional fractures are caused by widespread block-faulting episodes of Pennsylvanian age that broke the Alabama-Mississippi foreland into northwest-trending basement-involved blocks bounded predominantly by down-to-the-south normal faults.

Source rocks: The source of gas and oil in this play is unknown. Most likely, source rocks are the Upper Devonian Chattanooga Shale and (or) the Upper Mississippian Neal shale that are in fault contact with Cambrian and Ordovician carbonate reservoirs. The Neal shale, the thicker and more widespread of the two units, is as thick as 150 ft and extends across most of the Mississippi part of the basin and the southern end of the Alabama part of the basin. Total organic carbon values of the Neal shale are unknown but probably are greater than the 0.07–2.36 values (avg = 0.58) reported for undefined Upper Mississippian shale in Alabama. In contrast, the Chattanooga Shale is near its depositional limit and probably is present only in the Alabama part of the basin. The Chattanooga Shale has a maximum thickness in the Black Warrior Basin of approximately 30 ft. Total organic carbon values for the Chattanooga Shale in northern Alabama average about 16.3, and organic matter consists of type I and type II kerogen. A thin black shale at the top of the Stones River Group in northern Mississippi, which has a reported total organic carbon value of 2.02, is probably too local to be considered an important source rock.

Based on CAI, TAI, and vitrinite reflectance values, the Neal shale and Chattanooga Shale are in the zone of oil generation and the beginning of the zone of gas generation. Oil and wet to dry thermal gas are the expected hydrocarbon types.

Timing and migration: Oil and gas probably were generated from the Neal shale and Chattanooga Shale source beds in Late Pennsylvanian time when these rocks were deeply buried beneath a southward thickening wedge of orogenic sediments derived from an Ouachita and (or) Appalachian source. Probably, hydrocarbons were first generated at the southern end of the basin and migrated along fractures and carrier beds into available anticlines of frontal thrust sheets. Some of these hydrocarbons migrated northward, up the regional dip of the block-faulted foreland, into anticlines and fault traps. As the zones of oil and gas generation expanded northward with increasing burial, traps in the block-faulted foreland became charged with locally derived hydrocarbons.

Traps: Faulted rollover anticlines, tilted fault blocks, and positive flower structures are the major traps expected in the block-faulted part of the basin. Flower structures originated where transpressive stresses were applied to the block-faulted terrane. Ramp anticlines are major potential traps in the thrust-faulted margins of the basin. Closure on structural traps in the block-faulted and thrust-faulted parts of the play may cover an area as large as 10,000 acres. Stratigraphic traps characterized by erosional truncation and facies changes may be present on the homoclinal northern margin of the basin; however, they are probably smaller in area than the structural traps.

Probable seals for structural traps and facies-change traps consist of argillaceous micrite and dolomicrite, cherty dolomicrite, and sandy dolomicrite of the Upper Cambrian, Lower Ordovician, and Middle Ordovician carbonate sequences. Seals for truncation traps are unnamed Silurian limestone and shale(?) beds in northern Mississippi and the Chattanooga Shale in northern Alabama. Structural traps are most likely to be present between depths of 4,500 and 20,000 ft, whereas erosional truncation traps are most likely to be present between depths of 1,000 and 4,500 ft.

Exploration status: Between 250 and 300 holes have been drilled through all or part of the Cambrian and Ordovician carbonate sequence in the Black Warrior Basin. This drilling has resulted in the discovery of three one-well oil and (or) gas fields. The first of these fields to be discovered, the New Hope oil field in Monroe County, Mississippi, produced 7,813 barrels of oil and 395 thousand cubic feet of gas between September 1953 and October 1954. This field produced at depths between 4,753 and 4,756 ft. The Maben gas field was discovered in Oktibbeha County, Mississippi, in 1971 at a depth of 14,690-15,036 ft and produced more than 0.891 BCFG before abandonment in 1989. Discovered in 1976, a small pool in the Fairview field in Lamar County, Alabama has produced 0.523 BCFG of gas and 143 barrels of oil through 1991. This field produces from depths between 4,352 to 4,424 ft. All three fields produce from the "Snow zone" of the Stones River Group and are trapped by anticlinal structures. Several 12,000–20,000-foot deep dry holes were drilled to Cambrian and Ordovician objectives in the early 1990's.

Resource potential: This play has potential for several undiscovered gas and oil fields greater than 6 BCFG of gas and 1 MMBO. Small fields indicate that hydrocarbons are present in the Cambrian and Ordovician sequence. Moreover, numerous structures in the basin have not been tested for Cambrian and Ordovician accumulations, and areas having potential for truncation-trap accumulations have a low drilling density. Gas fields are much more likely to be found than oil fields because drilling depths to objectives in the prospective block-faulted and thrust-faulted terranes are greater than

10,000 ft. Four factors, in increasing order of importance, may limit the potential of the play: (1) reservoirs may be widely scattered and of low quality, (2) upper Paleozoic source beds may be inconveniently located for charging the reservoirs, (3) recent dry holes have tested some of the most attractive structures in the play, and (4) post-Pennsylvanian uplift and erosion of the highly block-faulted basin, and inadequate seals, may have permitted most of the gas and oil to escape.

6502. UPPER MISSISSIPPIAN SANDSTONE PLAY

The Upper Mississippian Sandstone Play is defined by gas and local oil trapped in Upper Mississippian deltaic and shallow-marine sandstone reservoirs by a variety of basement-involved fault blocks, combination traps, and stratigraphic traps. Stratigraphically, the play involves informally named sandstone units of the Upper Mississippian Parkwood Formation such as the Carter, Sanders, Lewis, Evans, Millerella, Abernathy, and Rea sandstones. The play is confirmed and extends across the entire Black Warrior Basin except for the northern margin where Mississippian rocks either crop out or subcrop beneath Cretaceous strata of the Mississippi Embayment. The sandstone reservoirs in the play are classified as conventional.

Reservoirs: Primary reservoirs in the play are sandstone of deltaic and distributary channel origin. The thickness of these sandstone reservoirs generally range from 30 to 50 ft, but, locally, individual reservoir units may be as thick as 150 ft. Commonly, sandstone reservoirs exhibit continuity for 2–5 mi along depositional strike and for 10–15 mi along depositional dip. The source of the sandstone is controversial. One group of geologists suggests a cratonic source area to the northwest in the vicinity of the Ozark Uplift, whereas another group suggests an orogenic source area to the southwest in the vicinity of the Ouachita Fold and Thrust Belt.

The sandstone reservoirs consist of quartzarenite containing 1–2 percent rock fragments and feldspar. Primary and secondary intergranular porosity are the dominant porosity types. Porosity values range from 5 to 20 percent, and permeability values range from 0.4 to 250 Md.   The lowest porosity and permeability values cited here are from a depth of 8,500 ft in the Siloam field (Clay County, Miss.), and they indicate a marked decrease in reservoir quality toward the southern end of the basin.

Tectonic fractures of extensional and transpressional origin may improve the reservoir quality of the sandstone. Extensional fractures are caused by widespread block-faulting episodes of Pennsylvanian age that broke the Alabama-Mississippi foreland into northwest-trending basement-involved blocks bounded predominantly by down-to-the-south normal faults. Transpressional fractures may have resulted from limited strike-slip motion between adjoining fault blocks.

Source rocks: Dark-gray to black shale of the Upper Mississippian Parkwood Formation, Floyd Shale, and Neal shale (slope to basin facies of the Bangor Limestone) are the likely sources of gas and oil in the play. The Floyd Shale and Neal shale are as thick as 500 ft and 200 ft, respectively. Published total organic carbon values from undefined Upper Mississippian shale in Alabama, probably the Parkwood Formation and Floyd Shale, range from 0.07 to 2.36 (avg 0.58). The organic matter consists of type II and type III kerogen. Although no analyses are available, the Neal shale is expected to have total organic carbon values between 1 and 5 and organic matter that consists of type II kerogen.

Based on CAI, TAI, and vitrinite reflectance values, the Parkwood Formation, Floyd Shale, and Neal shale are in the zone of oil generation and the beginning of the zone of gas generation. Oil and wet thermal gas are the expected hydrocarbon types.

Timing and migration: Oil and gas probably were generated from the Parkwood Formation, Floyd Shale, and Neal shale in Late Pennsylvanian time when these rocks were deeply buried beneath a southward-thickening wedge of orogenic sediments derived from an Ouachita and (or) Appalachian source. Hydrocarbons were first generated at the southern end of the basin and migrated northward across the block-faulted foreland, along fractures and carrier beds, into anticlines and fault traps. As the zones of oil and gas generation expanded northward with increasing burial, the traps in the block-faulted foreland became charged with locally derived hydrocarbons.

Traps: Structural traps and combination traps account for about 75 percent of the known gas and oil trapped in this play. The remainder of the gas and oil is trapped in facies-change stratigraphic traps. Faulted anticlines controlled by basement-involved fault blocks characterize the majority of the structural traps, whereas facies changes on an anticlinal nose or juxtaposed against a normal fault characterize the majority of the combination traps. Closure on prospective structural, combination, and stratigraphic traps covers an area between 1,000 and 9,000 acres.

Probable seals for the structural, combination, and facies-change traps are shale and argillaceous siltstone of the Upper Mississippian Floyd Shale and Parkwood Formation. The drilling depth to the reservoirs in the majority of the Upper Mississippian sandstone fields ranges between 1,000 and 5,000 ft. Several fields produce from Upper

Mississippian sandstone reservoirs between 8,500 and 10,000 ft. Potential structural, combination, and stratigraphic traps may be present as deep as 16,000 ft.

Exploration status: Several thousand holes have been drilled through all or part of the Upper Mississippian sequence in the Black Warrior Basin. Between 1926 and January 1992, approximately 145 gas fields and 20 oil fields were discovered in the Upper Mississippian sandstone play. Most of the fields are in a 10-country area (Fayette, Lamar, Marion, Pickens, and Walker Cos., Ala.; Chickasaw, Clay, Lee, Lowndes, and Monroe Cos., Miss.) in the central part of the basin. The Carter sandstone is the primary gas reservoir.

Through 1991, approximately 1 TCFG (85 percent of basin total) and 10 MMBO (95 percent of basin total) have been produced from Upper Mississippian sandstone reservoirs. The five largest fields discovered in the play are: Corinne, Monroe Co., Miss., discovery date 1972, depth 5,000–5,700 ft, ultimate recovery (Upper Miss. sandstone part) 378.6 BCFG; Blooming Grove, Fayette Co., Ala., discovery date 1975, depth 2,100 ft, ultimate recovery 169.6 BCFG; Musgrove Creek, Fayette Co., Ala., discovery date 1974, depth 2,500 ft, ultimate recovery 111.0 BCFG; McGee Lake, Lamar Co., Ala., discovery date 1979, depth 4,200–4,700 ft, ultimate recovery 105.9 BCFG; and 5) Splunge, Monroe Co., Miss., discovery date 1973, depth 1,700 ft, ultimate recovery 101.2 BCFG.

Most of the oil fields in the play have an ultimate recovery of less than 1 MMBO. Two exceptions are the Blowhorn Creek North field (Lamar Co., Ala., 2,000 ft-depth) which has an ultimate recovery of 14.5 MMBO, and the Maple Branch field (Monroe Co., Miss., 5,300 ft depth) which has an ultimate recovery of 2.0 MMBO.

Resource potential:**.** This play has potential for numerous undiscovered gas fields greater than 6 BCFG of gas and several undiscovered oil fields greater than 1 MMBO. Because 6 of the 39 largest gas fields in this play have been discovered since 1985, more gas (and probably oil) fields may remain to be found in the existing exploration area; however, the majority of the undiscovered gas in the play probably is in the deeper part of the basin at drilling depths between 8,000 and 16,000 ft. At these depths, reservoirs are expected to be distal-bar sandstone and possibly sandstone in previously unrecognized deltaic complexes. A major limiting factor to the play may be the paucity of sandstone reservoirs in the deeper parts of the basin. A second limiting factor is that sandstone reservoirs are expected to be thinner and of lower quality than reservoirs in the existing trend.

6503. PENNSYLVANIAN SANDSTONE PLAY

The Pennsylvanian Sandstone Play is defined by gas trapped in Lower(?) Pennsylvanian fluvial, deltaic, and shallow-marine sandstone reservoirs by a variety of basement-involved fault blocks, combination traps, and stratigraphic traps. Stratigraphically, the play involves informally named sandstone units of the Lower(?) Pennsylvanian Pottsville Formation such as the Benton, Chandler, Fayette, Nason, Robertson, and Robinson sandstones. The play is confirmed and extends across the entire Black Warrior Basin except for the northern part where Pennsylvanian rocks either crop out or subcrop beneath Cretaceous strata of the Mississippi embayment. The sandstone reservoirs in the play are classified as conventional.

Reservoirs: Primary reservoirs in the play are sandstone of deltaic, distributary channel, fluvial, and shallow-marine origin. The thickness of these sandstone reservoirs generally ranges from 30 to 50 ft, but, locally, individual reservoir units may be as thin as 9 ft and as thick as 100 ft. The source of the sandstone is controversial. One group of geologists suggests that the Appalachian Fold and Thrust Belt is the source area, whereas another group suggests that the Ouachita Fold and Thrust Belt is the source area.

The sandstone reservoirs consist of litharenite and sublitharenite containing 10–18 percent metamorphic rock fragments and 2–6 percent feldspar. Primary and secondary intergranular porosity are the dominant porosity types. Locally, moldic secondary porosity may be important. Porosity values range from 1.2 to 14.7 percent. No permeability values are reported in the literature. Porosity and probably permeability values probably decrease toward the more deeply buried southern part of the basin.

Tectonic fractures of extensional and transpressional origin may improve the reservoir quality of the sandstone. Extensional fractures are caused by widespread block faulting episodes of Pennsylvanian age that broke the Alabama-Mississippi foreland into northwest-trending, basement-involved blocks bounded predominantly by down-to-the-south normal faults. Transpressional fractures may have resulted from limited strike-slip motion between adjoining fault blocks.

Source rocks: Coal beds and dark-gray carbonaceous shale in the Lower(?) Pennsylvanian Pottsville Formation are the sources of gas. Coal beds are widely distributed across most of the Alabama part of the basin where their net thickness ranges from 30 to 50 ft. In contrast, the only documented coal beds in Mississippi are in a 400-square mile part of Clay County where their net thickness is 0–22 ft. The organic matter in the coal beds and shale consists of type III kerogen.

Based on vitrinite reflectance values, coal beds in the Pottsville Formation are in the zone of oil generation and in the beginning of the zone of gas generation zone. Dry gas is the expected hydrocarbon type because of the abundance of type III kerogen.

Timing and migration: Gas probably was generated from coal beds in the Pottsville Formation in Late Pennsylvanian time when these rocks were buried beneath a southward-thickening wedge of orogenic sediments derived from an Ouachita and (or) Appalachian source. Gas from the coal beds was first generated at the southern end of the basin and migrated northward across the block-faulted foreland, along fractures and carrier beds, into anticlines and fault traps. As the zone of gas generation expanded northward with increasing burial, the traps in the block-faulted foreland became charged with locally derived gas.

Traps: Structural traps and combination traps account for most of the known gas trapped in this play. They cover an area between 1,600 and 7,200 acres. Many of the structural traps are faulted anticlines controlled by basement-involved fault blocks. Although unrecognized to date, facies-change and diagenetic types of stratigraphic traps probably are present in this play.

Probable seals for the structural, combination, and stratigraphic traps are shale and argillaceous siltstone of the Lower(?) Pennsylvanian Pottsville Formation. The drilling depth to the reservoirs in the Pennsylvanian sandstone fields ranges from 2,200 ft to 4,750 ft. Structural, combination, and stratigraphic traps may be present as deep as 15,000 ft.

Exploration status: Several thousand holes have been drilled through all or part of the Pennsylvanian sequence in the Black Warrior Basin. Between 1909 and January 1992, 4 gas fields and 21 gas pools (in Mississippian sandstone fields) were discovered in the Pennsylvanian sandstone play. These fields and pools are located in a five-county area (Fayette, Lamar, and Pickens Cos., Ala.; Clay and Monroe Cos., Miss.) in the central part of the basin. Except for the Sneads Creek and Woolbank Creek fields in Pickens County, Alabama, the Pennsylvanian sandstone fields and pools are distributed among the Upper Mississippian sandstone fields. Most of the gas is produced from undefined sandstone reservoirs in the Pottsville Formation.

Through 1991, approximately 77 BCFG (7 percent of the basin total) and 0.06 MMBO (0.5 percent of the basin total) have been produced from Pennsylvanian sandstone reservoirs. The three largest fields discovered in the play are: Corinne, (Monroe Co., Miss.), discovery date 1972, depth 2,700 ft, ultimate recovery (Pennsylvanian sandstone part) 126.1 BCFG; Sneads Creek, (Pickens Co., Ala.), discovery date 1988, depth 2,700 ft, ultimate recovery 58.0 BCFG; and Woolbank Creek, (Pickens Co., Ala.), discovery date 1985, depth 2,700 ft, ultimate recovery 50.4 BCFG.

Resource potential:. This play has potential for numerous undiscovered gas fields greater than 6 BCFG of gas. No undiscovered oil fields greater than 1 MMBO are expected in the play. Because two of the six largest gas fields in the play have been discovered since 1985, there may be more to be found. Moreover, location of these recently discovered fields south of the main Upper Mississippian sandstone and Pennsylvanian sandstone exploration trend suggests that most of the undiscovered gas in the play resides in the deeper part of the basin at drilling depths between 4,000 and 15,000 ft. Reservoirs at these depths are expected to be of lower quality than reservoirs in the existing trend. Three factors, in increasing order of importance, may limit the potential of the play: (1) coal beds, which are the source of the gas, may be very thin to absent in the southern part of the basin in Mississippi; (2) sandstone reservoirs may be widely scattered and of low quality in the southern part of the basin; and (3) post-Pennsylvanian uplift and erosion of the highly block faulted basin, and inadequate seals, may have permitted most of the gas to escape.

6505. DEVONIAN CHERT AND CARBONATE PLAY (HYPOTHETICAL)

The Devonian Chert and Carbonate Play is defined by gas and local oil trapped in Devonian tripolitic chert and fractured cherty limestone reservoirs by basement-controlled fault blocks, ramp anticlines associated with frontal thrust faults, and erosional truncation. Stratigraphically, the play involves unnamed Lower, Middle, and Upper Devonian strata that are equivalent to all or part of the Arkansas Novaculite in the Arkoma Basin of Arkansas and Oklahoma (Province 062). The play is hypothetical and extends across all of the Black Warrior Basin except for its northeasternmost part in Alabama and northernmost part in Mississippi where the Devonian chert and limestone sequence has been truncated by Late Devonian uplift and erosion. The chert and limestone reservoirs in the play are classified as conventional.

Reservoirs: Primary reservoirs are tripolitic chert that has secondary intercrystalline porosity and vuggy limestone formed by prolonged subaerial exposure during Late

Devonian uplift and erosion. Tectonic fractures of extensional and compressional origin have improved the quality of the zones of secondary porosity and, in some case, may be the sole cause of the reservoir. Zones of secondary intercrystalline porosity, vuggy porosity, and (or) fracture porosity are capable of producing high-quality reservoirs in the Devonian chert and limestone sequence; however, where identified, they are usually very discontinuous and heterogeneous.

Compressional fractures are generally confined to tectonic ramps, zones of detachment in frontal thrust faults, and local zones of transpression between basement-involved fault blocks. In contrast, extensional fractures are caused by widespread block-faulting episodes of Pennsylvanian age that broke the Alabama-Mississippi foreland into northwest-trending basement involved blocks bounded predominantly by down-to-the-south normal faults.

Source rocks: The Upper Devonian Chattanooga Shale and Upper Mississippian Neal shale, in fault contact with chert and limestone reservoirs, are the most likely sources of gas and local oil in this play. The Neal shale, the thicker and more widespread of the two units, is as thick as 150 ft, and it extends across most of the Mississippi part of the basin and the southern end of the Alabama part of the basin. Total organic carbon values of the Neal shale are unknown but probably are greater than values (0.07–2.36, avg 0.58) reported for undefined Upper Mississippian shale in Alabama. In contrast, the Chattanooga Shale is near its depositional limit and probably is present only in the Alabama part of the basin. The Chattanooga Shale has a maximum thickness in the Black Warrior basin of approximately 30 ft. Total organic carbon values for the Chattanooga Shale in northern Alabama average about 16.3, and its organic matter consists of type I and type II kerogen. A thin black shale at the top of the Middle Ordovician Stones River Group in northern Mississippi, which has a reported total organic carbon value of 2.02, is probably too local to be considered an important source rock.

Based on CAI, TAI, and vitrinite reflectance values, the Neal shale and Chattanooga Shale are in the zone of oil generation and the beginning of the gas-generation zone. Oil and wet to dry thermal gas are the expected hydrocarbon types.

Timing and migration: Oil and gas probably were generated from the Neal shale and Chattanooga Shale source beds in Late Pennsylvanian time when these rocks were deeply buried beneath a southward thickening wedge of orogenic sediments derived from an Ouachita and (or) Appalachian source. Hydrocarbons were first generated at the southern end of the basin and migrated along fractures and carrier beds into available anticlines of frontal thrust sheets. Some of these hydrocarbons migrated northward, up the regional dip of the block-faulted foreland, into anticlines and fault traps. As the zones of oil and gas generation expanded northward with increasing burial, the traps in the block-faulted foreland became charged with locally derived hydrocarbons.

Traps: Faulted rollover anticlines, tilted fault blocks, and positive flower structures are the major traps expected in the block-faulted part of the basin. Flower structures originated where transpressive stresses were applied to the block-faulted terrane. Ramp anticlines are potential traps in the thrust-faulted margins of the basin. Closure on structural traps in the block-faulted and thrust-faulted parts of the play may cover an area as large as 10,000 acres. Erosional truncation traps may be present on the homoclinal northern margin of the basin; however, they are probably smaller in area than the stratigraphic traps.

Probable seals for structural traps and truncation traps are unnamed Silurian limestone and shale(?) beds in Mississippi and the Chattanooga Shale in Alabama. Structural traps are most likely to be present between the depths of 4,000 and 18,000 ft, whereas erosional truncation traps are most likely to be present between the depths of 1,000 and 4,000 ft.

Exploration status: Between 100 and 150 holes have been drilled through all or part of the Devonian chert and limestone sequence in the Black Warrior Basin. Two small Devonian gas pools and one small oil pool have been discovered in the basin since 1980. The major production in all three fields is from Upper Mississippian sandstone reservoirs. The Devonian oil pool in the McKinley Creek field (Monroe Co., Miss.) was discovered in 1980 at a depth of about 5,500 ft. It has produced 6,014 barrels of oil and over 0.133 BCFG through 1991. The two Devonian gas pools, discovered in 1983 at a depth of 5,000 ft, are in the Mt. Zion and Yellow Creek fields of Lamar County, Alabama. Through 1991, cumulative gas production of these Devonian pools in the Mt. Zion and Yellow Creek fields are 0.407 BCFG and 0.397 BCFG, respectively. The recently abandoned ARCO No. 1 Bobbie drill hole in Calhoun County, Mississippi is reported to have yielded excellent gas shows in Devonian strata between 13,000 and 14,000 ft.

Resource potential:. The play has potential for several undiscovered gas and oil fields greater than 6 BCFG or 1 MMBO. Small fields indicate that hydrocarbons are present in the Devonian chert and limestone sequence. Moreover, numerous structures in the basin have not been tested for Devonian chert and limestone accumulations, and areas having potential for truncation-trap accumulations have a low drilling density. Gas fields are much more likely to be found than oil fields because drilling depths to objectives in the prospective block-faulted and thrust-faulted terranes are greater than 10,000 ft. Four factors, in increasing order of importance, may limit the potential of the play: (1) reservoirs may be widely scattered and of low quality, (2) upper Paleozoic source rock may be inconveniently located for charging the reservoirs, (3) recent dry holes have tested some of the most attractive structures in the play, and (4) post-Pennsylvanian uplift and erosion of the highly block faulted basin, and inadequate seals, may have permitted most of the gas and oil to escape.

UNCONVENTIONAL PLAYS

Coalbed Gas Plays

By Dudley D. Rice and Thomas M. Finn

Four coalbed gas plays are identified in the Black Warrior Basin (065). These are the Black Warrior Basin Recharge Play (6550), the Black Warrior Basin–Southeastern Basin Play (6551), the Black Warrior Basin–Coastal Plain Play (6552), and the Black Warrior Basin–Central and Western Basin Play (6553).

The Black Warrior Basin is located in Alabama and Mississippi. McFall and others (1986a) and Pashin (1991) described the controls and potential for coalbed gas in the Alabama portion of the Black Warrior Basin where all of the development has taken place. Details of geologic and engineering controls on coalbed gas production in the Cedar Cove area are given by Ellard and others (1992) and Sparks and others (1993). The Gas Research Institute conducted a multi-year research program at the Rock Creek Site within the Oak Grove field. Reservoir characterization of coal beds in the Rock Creek Site is provided by Young and Paul (1993) and in issues of the Gas Research Institute's Quarterly Review of Methane from Coal Seams Technology from 1983. Henderson and Gazzier (1989) and Ericksen (1992) provide some information on the coalbed gas potential of the Mississippi portion of the basin. The effects of surface discharge of produced waters from coalbed gas wells are reported by O'Neil and others (1993) and Shepard and others (1993).

The upper part of the Lower Pennsylvanian Pottsville Formation contains economically important coal beds, which are assigned to several widespread coal groups. The coal groups form the upper part of regressive sequences that coarsen upward from marine mudstone to nonmarine sandstone and thicken to the southeast. The potential for coalbed gas occurs in five groups, in ascending order: Black Creek, Mary Lee, Pratt, Cobb, and Gwin. The Mary Lee Coal Group is the most important for underground mining.

Individual coal beds are generally thin (less than 3 ft) throughout the basin, although the Blue Creek Bed of the Mary Lee Group is locally more than 9 ft thick. The coal beds are most abundant and thickest in the southeastern part of the basin where the presence of fluvial-deltaic platforms favored peat accumulation. As many as 40 individual coal beds are present in this part of the basin, and the net coal thickness is as much as 32 ft. The coal-bearing section dips gently to the southwest and the Black Creek Coal Group is at depths greater than 4,000 ft in the southern part of the potential area. About the western two-thirds of the basin is covered by Cretaceous and younger sediments of the Gulf Coastal Plain, which unconformably overlie the Pottsville.

The highest coal rank in the basin, which is low-volatile bituminous for the Mary Lee Group, occurs in a “bull’s-eye” pattern along the border of Tuscaloosa and Jefferson Counties, Alabama, in the southeast part of the basin. This area generally coincides with the area of abundant and thick coal beds, and the present-day depth of burial is less than 3,000 ft. The coal ranks decrease away from this area (southwest, northeast, and northwest) and are as low as high-volatile C bituminous rank in Mississippi. The higher ranks in the southeastern part of the basin are the result of a combination of maximum depth of burial and higher paleoheat flow. Maximum depth of burial probably occurred during late Paleozoic time, and as much as 8,000 ft of erosion has probably taken place since that time. In addition, higher paleoheat flows might have resulted from hydrothermal flow in fractured strata adjacent to the Appalachian Orogen.

The produced coalbed gases in the Black Warrior Basin consist mainly of methane with less than 1 percent heavier hydrocarbons and less than 1 percent CO_2. The gases are interpreted to be mainly thermogenic and were generated during the time of maximum burial and heat flow, the late Paleozoic. Following uplift and erosion, some of the original thermogenic gas probably degassed, particularly at shallower depths. Mixing of relatively recent biogenic gas, which was generated in association with active groundwater flow, occurred in the shallower coal beds near the Appalachian Orogen.

Folds and thrust faults are restricted to the southeastern part of the basin and strike northeast. Strata in the anticlines, such as the Blue Creek Anticline, are intensely fractured as compared with those in the rest of the basin. Normal faults, which are generally oriented to the northwest, are abundant in the Black Warrior Basin. These faults are related to extensional tectonics and form a series of linear to arcuate horst and graben blocks. Syndepositional movement on these faults and folds strongly affected sedimentation, coalification, hydrology, and productivity.

In addition to the major normal fault system, two distinct sets of cleats are developed in the Pottsville coals. One dominant set, which is oriented to the northeast, has been reported throughout the Alabama portion of the basin. Another set is developed locally in the vicinity of Blue Creek Anticline and Opossum Valley Thrust Fault and the face cleats strike to the northwest.

The Pottsville Formation is an unconfined aquifer, and the coal beds are the most permeable units in the eastern part of the basin. Recharge of the Pottsville is at outcrops along the Birmingham Anticlinorium (part of the Appalachian orogen) and groundwater flow is toward the northwest. Discharge takes place along the Black Warrior River and its tributaries. Potentiometric lows exist in areas of underground coal mining and coalbed gas production. In general, TDS of the waters associated with the coal beds increase with depth and sometimes exceed 30,000 ppm. However, several northwest trending plumes of fresh water, characterized by low TDS (<3,000 ppm), extend out into the basin adjacent to the Birmingham Anticlinorium. This fresh-water flow is controlled by northwest-oriented faults and fractures. Daily water production from individual wells can exceed 1,200 barrels per day in these areas of increased permeability. Gas production rates can also be higher. In the western two-thirds of the basin, coastal plain sediments unconformably overlie the Pottsville and intercept meteoric recharge.

In the Black Warrior Basin, water production and disposal is considered to be a coal-mining activity. Most of the produced water is discharged into the Black Warrior River and its tributaries. Monitoring studies have indicated that the discharge has not significantly affected the river's water quality or biologic communities.

Desorbed gas contents of the Pottsville coal beds are similar to those of the Central Appalachian Basin and generally increase with depth and rank. The gas contents range from about 125 to 680 Scf/t. The highest values occur in the southeastern part of the basin ("bull's eye" area) where high ranks occur at shallow depth creating a very favorable area for in-place and recoverable coalbed gas resources.

Pressure gradients in the upper Pottsville Formation are generally at hydrostatic gradient (0.43 psi/ft). The exception is underground coal mining areas, such as the Oak Grove and Jim Walter mines, where pressures as low as 0.32 psi/ft are reported.

The in-place coalbed gas resources in the Alabama portion of the Black Warrior Basin are estimated to be about 20 TCF. This estimate is for the Black Creek, Mary Lee, Pratt, and Cobb Coal Groups and does not include the younger Gwin Group, which has commercial production. More than 70 percent of the in-place resource is estimated to be contained in the lower Black Creek and Mary Lee coal groups.

Alabama ranked 12th in the country in terms of coal production in 1991 with more than 60 percent of the total coming from underground mines. Tuscaloosa followed by Jefferson were the most active counties for underground mining. The major target for underground mining is coal beds in the Mary Lee Group; large mined-out areas occur in Walker, Jefferson, and Tuscaloosa Counties. In 1988, only West Virginia emitted more methane than Alabama in association with underground coal mining.

The first coalbed gas production in the Black Warrior Basin was associated with underground coal mines. Production began in Oak Grove degasification field in 1981 and in Brookwood degasification field in 1982. In these two areas, hydraulically fractured vertical wells, horizontal in-mine wells, and gob wells are used to capture coalbed gas in association with mining. Since this earlier mining-related activity, development has rapidly expanded away from the mining areas. However, the development is restricted to the southeast part of the basin where coal beds are thicker, more numerous, and of higher rank. In 1993, more than 2,900 wells produced about 104 BCF of coalbed gas in the Alabama portion of the basin. In 1992, 91 BCF of coalbed gas was produced from about the same number of wells, which accounted for about 28 percent of the natural gas production in the State. In comparison, 36 BCFG was produced in 1990 and 68 BCFG in 1991. Production is from 16 degasification fields (Big Sandy, Blue Creek, Boone Creek, Brookwood, Cedar Cove, Deerlick Creek, Holt, Little Buck Creek, Little Sandy Creek, Moundville, Oak Grove, Peterson, Pleasant Grove, Robinson's Bend, Taylor Creek, and Wolf Creek). In 1993, the most productive degasification fields, in descending order, were Blue Creek, Cedar Cove, Brookwood, Oak Grove, and Deerlick Creek. New drilling over the past 2 years has substantially decreased, and the emphasis has been on optimizing production with recompletions. According to the Gas Research Institute, the Black Warrior Basin had coalbed gas reserves of about 2,900 BCF at the end of 1993, which is second only to the San Juan Basin. Pipelines have been added in the basin to accommodate this increased production.

The area for potential additions to reserves of coalbed gas in the Black Warrior Basin, where the Pottsville coal beds are deeper than 500 ft, extends from northwestern Alabama to northeastern Mississippi. However, the highest potential is in the southeastern part of the basin (Alabama) where the Pottsville coal beds are more abundant, thicker, of higher rank, and at relatively shallow depths. The properties related to coalbed gas potential in Mississippi are less well documented, but can be inferred from regional trends.

6550. BLACK WARRIOR BASIN RECHARGE PLAY,
6551. BLACK WARRIOR BASIN–SOUTHEASTERN BASIN PLAY,
6552. BLACK WARRIOR BASIN–COASTAL PLAIN PLAY,
6553. BLACK WARRIOR BASIN–CENTRAL AND WESTERN BASIN PLAY (HYPOTHETICAL)

Plays 6550, 6551, and 6552 occur where (1) the Black Creek Coal Group is deeper than 500 ft , (2) Mary Lee and older coal groups have rank equal to and greater than about high-volatile A bituminous, and (3) 15 or more coal beds are present in the Black Creek through Cobb interval. In addition, present production is restricted to these three plays.

The Black Warrior Basin Recharge Play (6550) parallels the Appalachian Orogen, includes the Blue Creek Anticline and Syncline, and is oriented in a northeast-southwest direction. This is part of the "bull's eye" area where the Pottsville coals are numerous, thick, of high rank, and at relatively shallow burial depths. The play area coincides with the northwest-trending intrusions of fresh water (as identified by low TDS content) into the basin. These fresh-water plumes are especially extensive in the area of the Blue Creek Anticline where enhanced permeability is developed. Depth of burial in the play increases to the southwest, and production has been established at depths from about 500 ft to 3,800 ft in the Cedar Cove and parts of Oak Grove and Brookwood fields. Similar to depth of burial, gas production from individual wells generally increases to the southwest. The potential for additional reserves in this play is good, although limited because of the extensive exploration and production that has taken place. Remaining potential exists at shallower depths in the northeast part of the play area and from unmined coal beds in mining areas.

The Black Warrior Basin–Southeastern Basin Play (6551) is northwest of the Black Warrior Basin Recharge Play (6550) where there is no significant fresh-water flow. Most of the play area is situated away from the "bull's-eye" area so that the coal beds are generally fewer and thinner and lower in rank than in the Recharge Play (6550). As is the case with the Recharge Play, the depth of burial increases in a southwestern direction with a corresponding general increase in daily production rates from individual wells. Production in this play has been established in the Blue Creek, Peterson, Deerlick Creek, Holt, and White Oak Grove degasification fields, and in parts of the Brookwood and Oak Grove degasification fields. The potential for additional reserves in this play is regarded as good and is only restricted by the limited development that has taken place to date.

The Black Warrior Basin–Coastal Plain Play (6552) is located to the southwest of the Southeastern Basin Play (6551); and the Pottsville coal beds probably have the same abundance, thickness, and rank. However, the coal beds are unconformably overlain by Cretaceous and younger coastal plain sediments, which are as thick as 6,000 ft adjacent to the Ouachita Orogenic Belt. Individual wells within the play are characterized by low production rates, generally less than 50 MCFGPD. Production in this play has been established in the Robinson Bend, Moundville, Little Sandy Creek, Big Sandy Creek, Taylor Creek, and Little Buck Creek fields. The potential for additional reserves in this play is estimated to be fair because of low permeability and possible undersaturation.

The Black Warrior Basin–Central and Western Basin Play (6553) covers a large part of the basin, but there has been limited exploration and no production has been established. The play area is characterized by a few, thin coal beds of low rank that are overlain by coastal plain sediments. In a well drilled in Clay County, Mississippi, specifically to evaluate the coalbed gas potential, only 7 ft of coal were recovered from the Pottsville interval. The coal was of relatively low rank (high-volatile A or B bituminous) with a probable high ash content. The desorption data indicated a gas content of only 100 to 110 Scf/ton. The potential for reserves in this play is regarded as fair to poor based on small coal resources and low rank associated with low gas content.

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